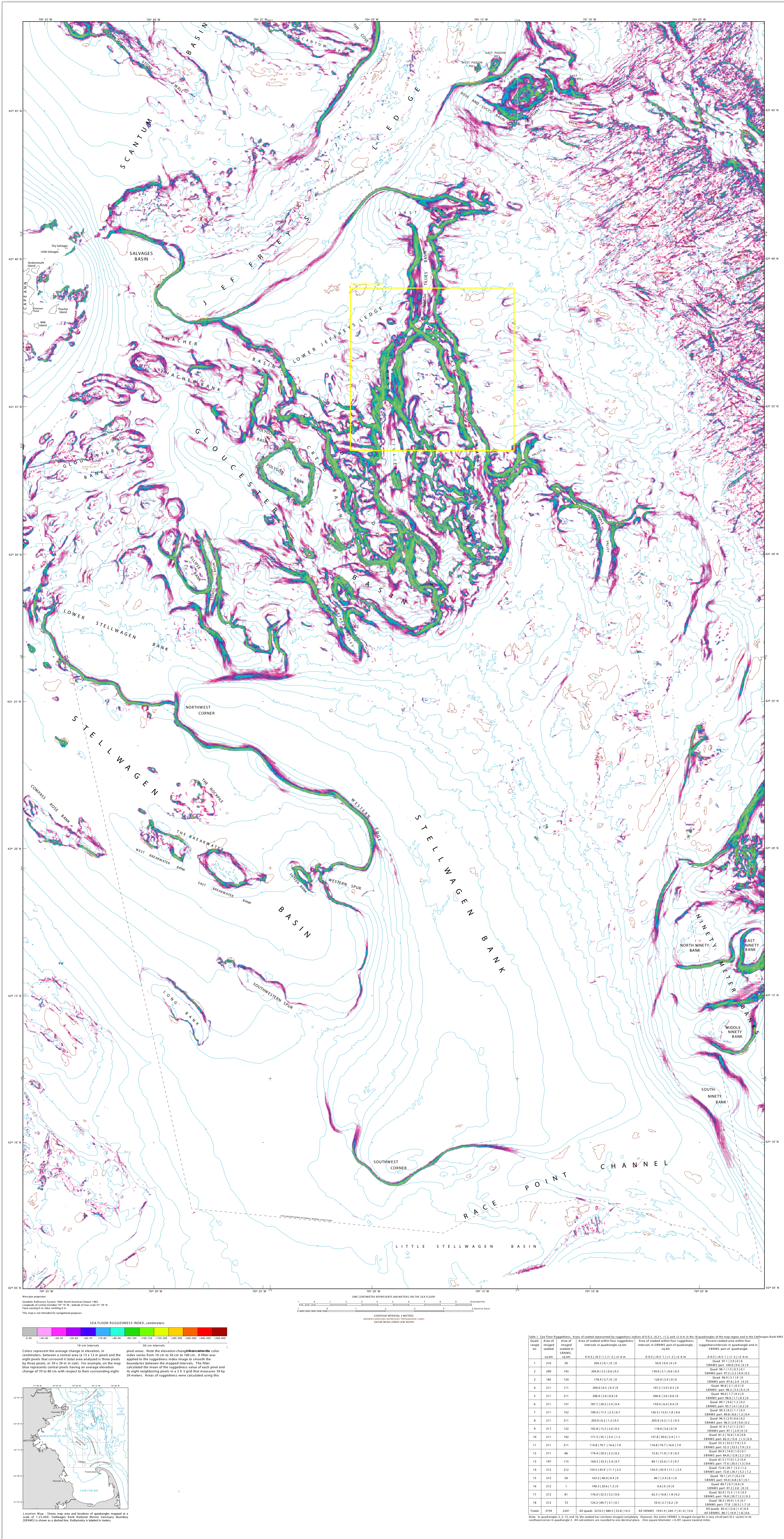![USGS science for a changing world]

Terrain Ruggedness Analysis and Distribution of Boulder Ridges in the Stellwagen Bank National Marine Sanctuary Region

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METHODS

The Terrain Ruggedness Index (TRI) shows the average change in elevation between a center cell (pixel) and its eight neighboring cells (pixels). On this map, pixel size is 13 meters square. Therefore, the TRI shows the average change in elevation between an area measuring 13 x 13 m and a surrounding area measuring 39 x 39 m. Average changes in elevation are shown here in ten-centimeter increments in the 0.3 to 1.0 meter range, in half-meter increments in the 1.0 to 2.0 meter range, and in one-meter increments in the 2.0 to >6.0 meter range. Average changes in elevation less than 30 centimeters are not shown.

The Terrain Ruggedness Index developed for this map is based on an index described by Riley and others (1999) that calculated the change in elevation between a grid cell and its eight neighboring grid cells by squaring the eight differences in elevation, averaging the result, and taking its square root. Here, the index has been modified to calculate the average of the absolute values of the eight differences in elevation, an approach we consider to be more straight forward than the method of Riley and others (1999). By comparison, a cell with an elevation value of 10, and neighboring grid cells with values of 11, 12, 13, 14, 15, 16, 17 and 18 would have a TRI value of 4.50 with the new method, rather than 5.05 with the Riley and others (1999) method. An example of the TRI equation used here is given in Figure 1.

$$TRI = [abs\{grid(0,0) - grid(-1,-1)\} + abs\{grid(0,0) - grid(0,-1)\} +$$
$$abs\{grid(0,0) - grid(1,-1)\} + abs\{grid(0,0) - grid(1,0)\} +$$
$$abs\{grid(0,0) - grid(1,1)\} + abs\{grid(0,0) - grid(0,1)\} +$$
$$abs\{grid(0,0) - grid(-1,1)\} + abs\{grid(0,0) - grid(-1,0)\}] / 8$$

| -1,-1	0,-1	1,-1
-1,0	0,0	1,0
-1,1	0,1	1,1

Figure 1: Terrain Ruggedness Index (TRI) for the Stellwagen Bank NMS region. If each square on the grid represents the location of a corresponding pixel value on the bathymetric image, then the TRI can be described by the above equation. Note: abs = absolute value; grid ( ) = the pixel's value from the given grid location.

- The TRI was applied to the digital bathymetric grids of the seafloor by running a macro in ArcMap's Visual Basic editing environment. The macro contained equivalent Visual Basic code for the equation shown in Figure 1.

- Artifacts of data collection were removed by hand editing and by applying a "mean" filter on the ruggedness image (Compare Figures 3, 5). The Neighborhood Statistics function in Spatial Analyst was used to calculate a mean TRI for a 3 x 3 pixel template of TRI values centered over each pixel in the image.

- The total areas of classes were calculated using the Histogram Tool in Spatial Analyst. This tool reports the number of pixels in each ruggedness class on the image. Average changes in elevation were shown in ten-centimeter increments in the 0.3 to 1.0 meter range (Fig. 4); in half-meter increments in the 1.0 to 2.0 meter range (Fig. 6); and in one-meter increments in the 2.0 to >6.0 meter range (Fig. 7). Total areas for each class can be determined by multiplying the number of pixels in the class by the image pixel size of 13 meters x 13 meters. Area statistics for classes in the Stellwagen Bank NMS region were totaled and entered into Table 1.

Reference: Riley, S.J., DeGloria, S.D., and Elliot, R., 1999, A terrain ruggedness index that quantifies topographic heterogeneity: Intermountain Journal of Sciences, Vol. 5, No 1-4, p. 23-27.

SUMMARY

- Seabed geomorphology in the Stellwagen Bank NMS region, off Boston, Massachusetts is highly variable due to its glacial origin. Seabed variability provides the framework for the region's wide range of habitats and high biodiversity.

- This map combines digital sun-illuminated topographic imagery with an analysis of seabed ruggedness for an area of 3759 sq km. Sun elevation and angle are 45 degrees and 350 degrees, respectively.

- The Terrain Ruggedness Index (TRI) calculates the average difference in elevation between a small area (a central pixel of 13 x 13 m) and its surrounding area (8 neighboring pixels).

- In order to delineate small features from large features, average differences in seabed elevation are shown on the map as follows: in 10-cm increments in the >0.3 to 1 m range, in 50-cm increments in the >1 to 2 m range, in 100-cm increments in the >2 to 6 m range

- Gray tones on the map have low TRIs of 0 to 30 cm.

- TRIs in the >0.3 to 1 m range (Fig. 4) represent small scale features such as: boulder ridges; mud-draped gravel mounds; elongate iceberg scours; sand dunes; and gentle slopes of banks, valleys, and basins.

- TRIs in the >1 to 2 m range (Fig. 6) represent flanks of banks and bedrock hills and a few boulder ridges.

- TRIs in the >2 to 6 m range (Fig. 7) represent the steepest flanks of banks and bedrock hills.

- The resolution of bathymetric data determines the resolution of seabed features that can be recognized using TRI analysis. TRIs derived from 13-meter pixel data are not comparable with TRI values of the same magnitude derived from 10-meter pixel data.

- Seabed terrains with similar TRIs do not necessarily represent similar bottom types. See the companion "Boulder Ridges and Bedrock Outcrops" poster.

- Without supporting video and photographic imagery, the Terrain Ruggedness Index does not allow reliable interpretation or comparison of seabed features.
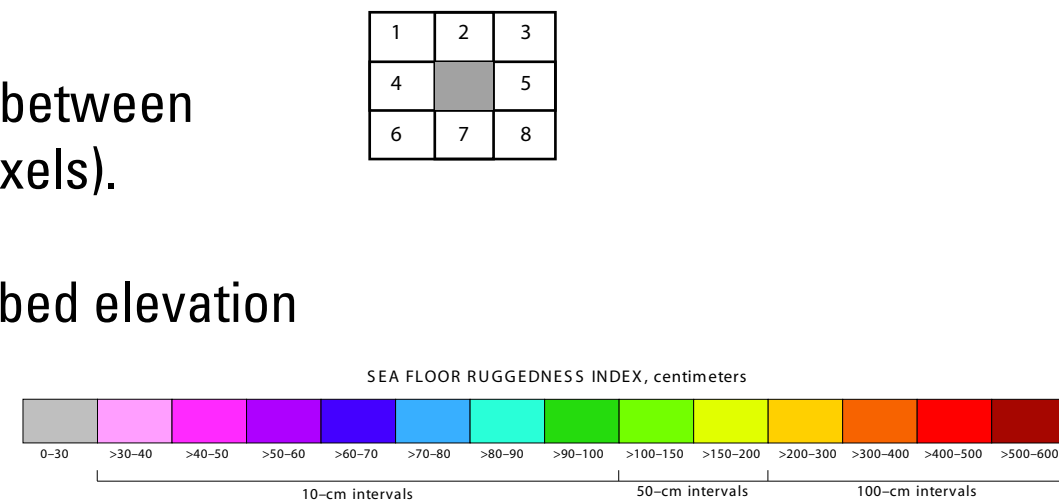
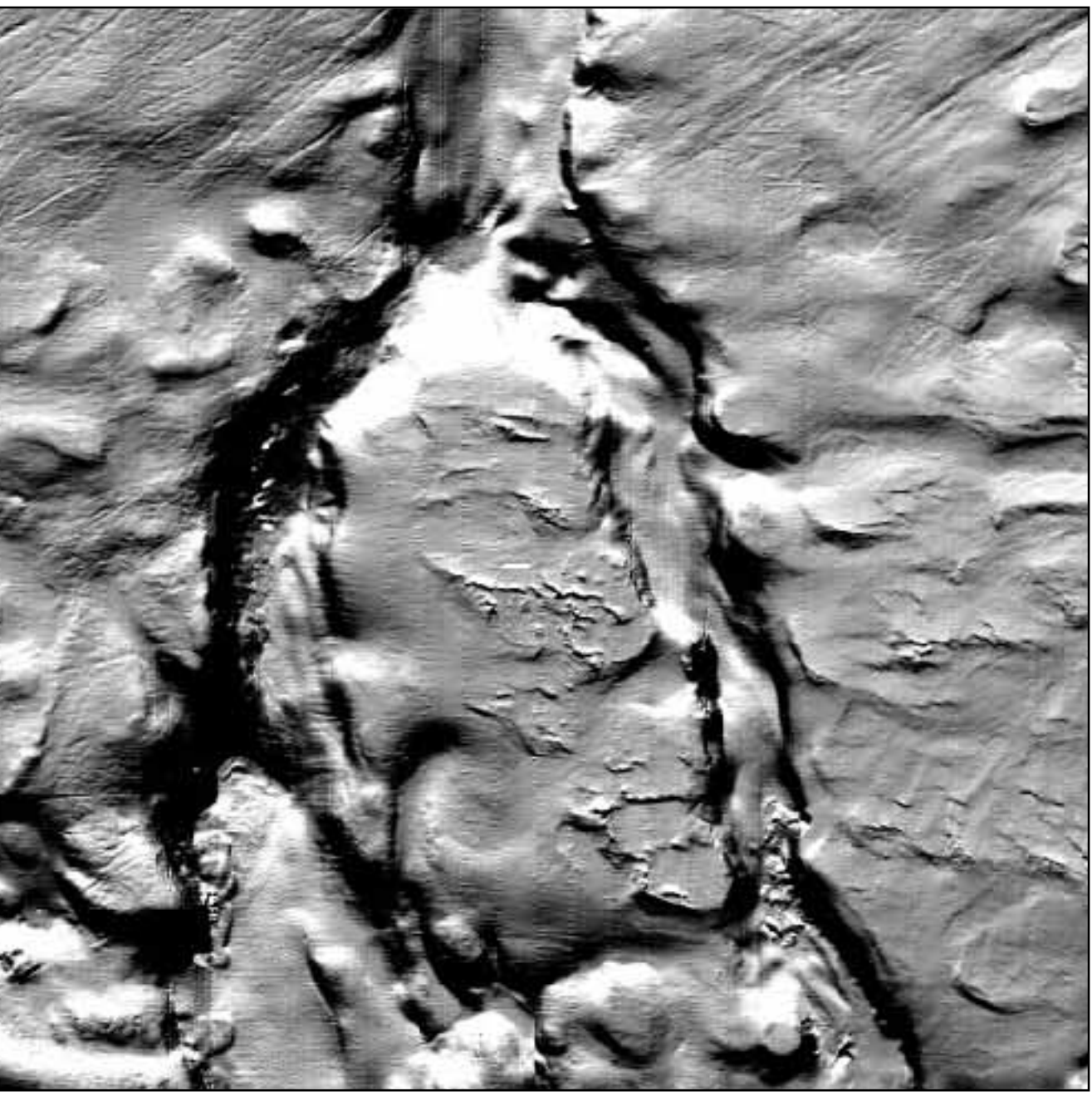## SEABED RUGGEDNESS OF TILLIES BANK

Figure 2: Sun-illuminated topography of the northern part of Tillies Bank showing rugged glaciated terrain. Vertical exaggeration 4x. Scale 1:60,000.
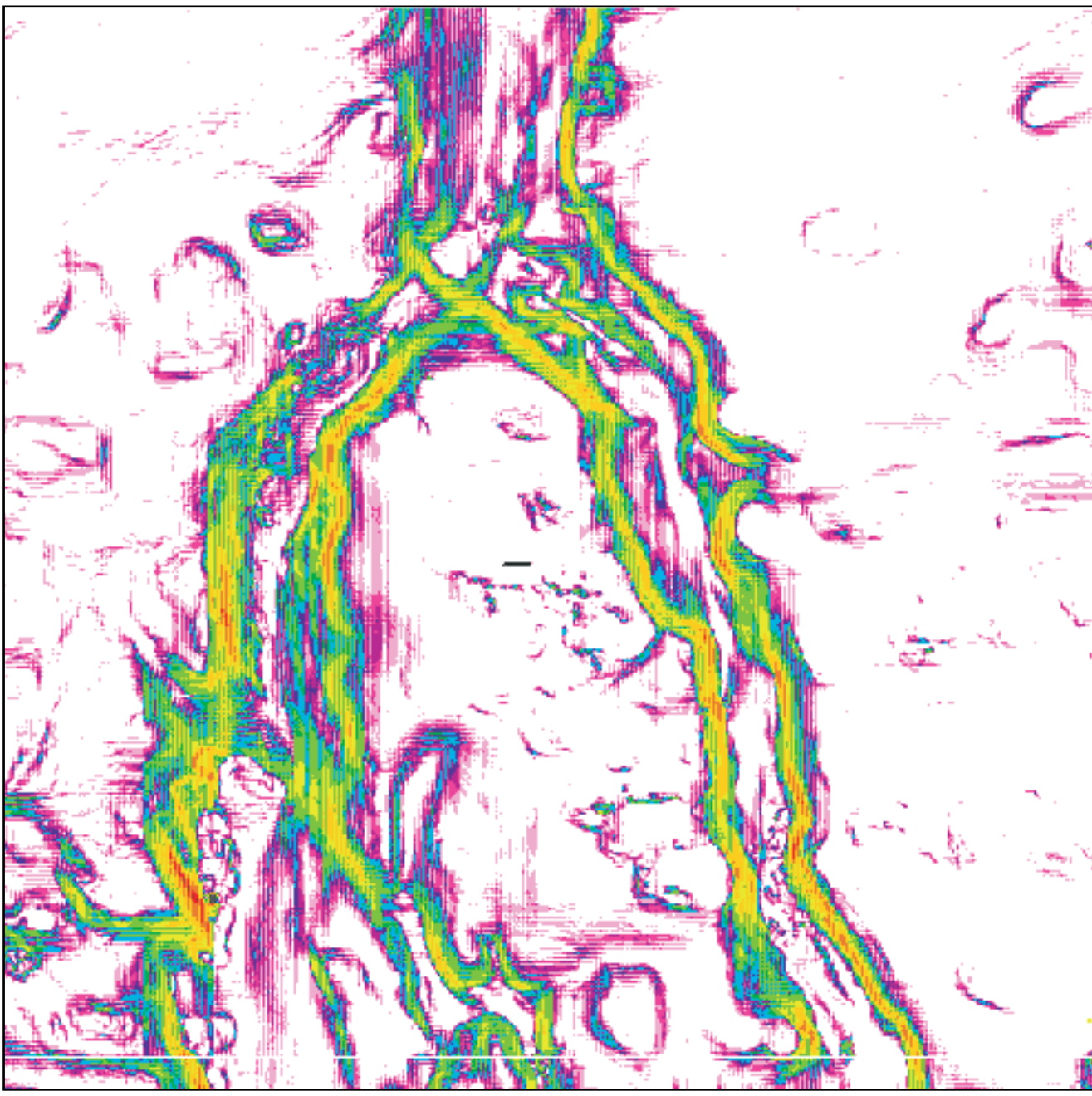

Figure 3: Sun-illuminated topography of the northern part of Tillies Bank with Terrain Ruggedness Indices (TRIs) before removal of artifacts with a "mean" filter. Compare to Figure 5.
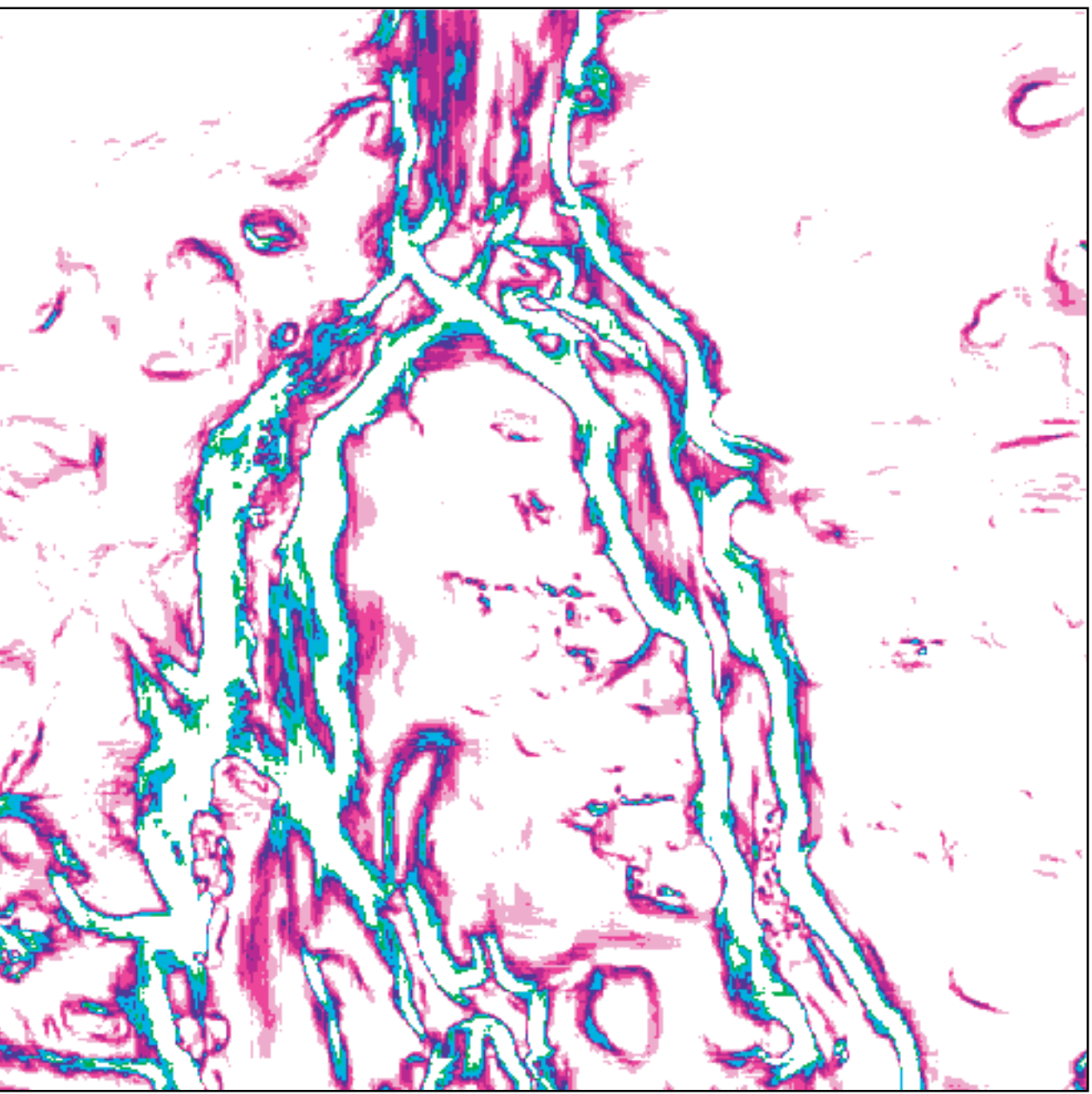

Figure 4: Sun-illuminated topography of the northern part of Tillies Bank with Terrain Ruggedness Indices (TRIs) representing average changes in elevation in 10-cm increments in the 30 to 100 cm range. Boulder ridges are the dominant features on the top of the bank. Most boulder ridges in the Stellwagen Bank NMS region have TRIs in the 30 to 100 cm range.
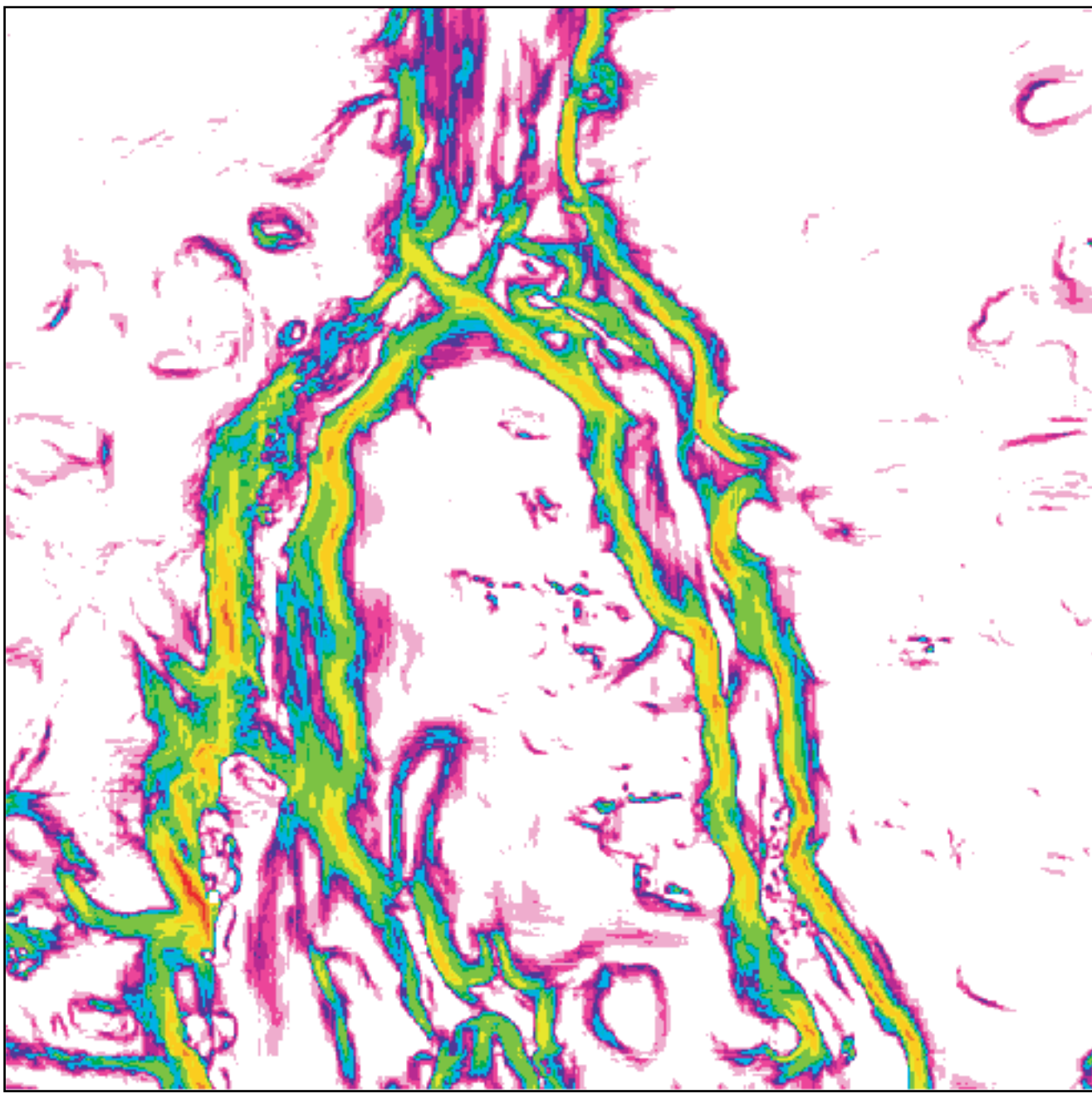

Figure 5: Sun-illuminated topography of the northern part of Tillies Bank with Terrain Ruggedness Indices (TRIs) after removal of artifacts with a "mean" filter. Compare to Figure 3.
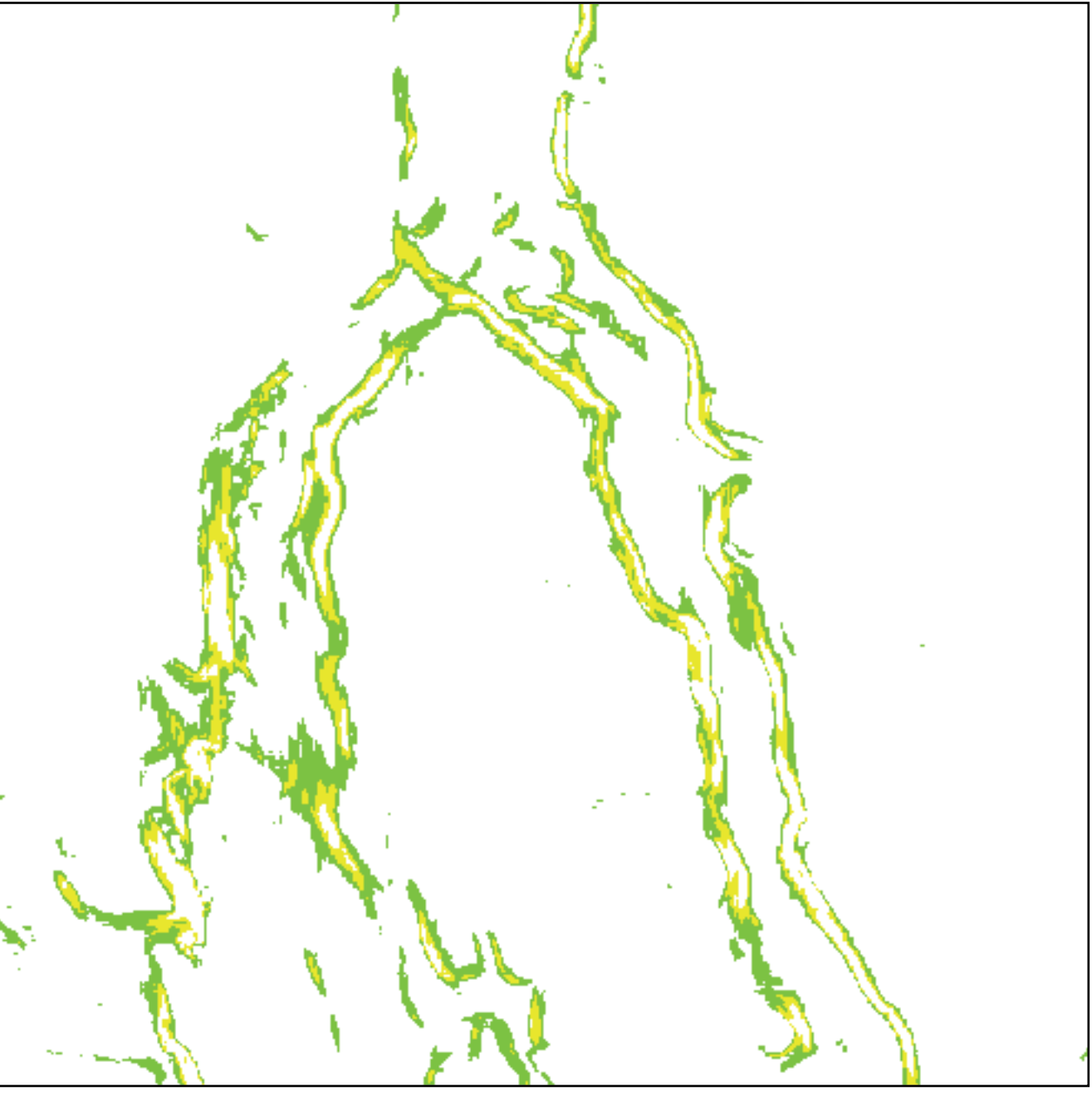

Figure 6: Sun-illuminated topography of the northern part of Tillies Bank with Terrain Ruggedness Indices (TRIs) representing average changes in elevation in 50-cm increments in the 100 to 200 cm range. There are only a few boulder ridges in the image with TRIs in the 100 to 200 cm range.
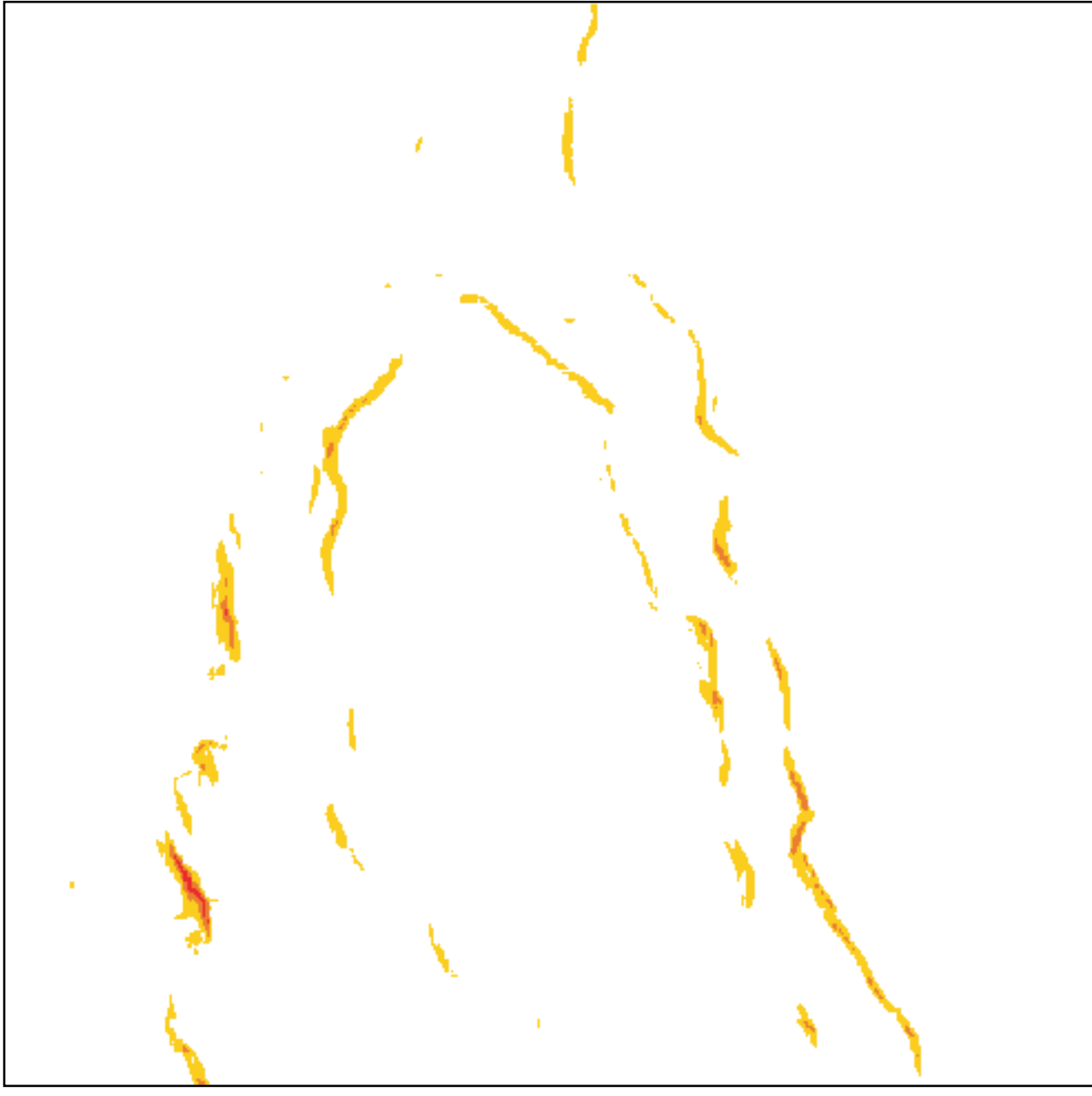

Figure 7: Sun-illuminated topography of the northern part of Tillies Bank with Terrain Ruggedness Indices (TRIs) representing average changes in elevation in 100-cm increments in the 200 to 600 cm range. They are located on the steepest flanks of the bank and adjacent valleys. There are no boulder ridges with TRIs in this range.